INTERMEDIATE AND FAR FIELDS OF A REFLECTOR ANTENNA ENERGIZED BY A HYDROGEN SPARK-GAP SWITCHED PULSER

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Abstract

Previously, the design, fabrication and testing of a pulser with a parabolic reflector antenna, known as Prototype Impulse-Radiating Antenna (IRA) had been presented [1]. The paraboloidal reflector was fed by a TEM structure that in-turn was energized by a $\pm$ 60 kV, ~ 100 atm. hydrogen switch operating in a burst mode at up to 200 Hz. The TEM structure also incorporated an electromagnetic lens to ensure a near-ideal spherical TEM wavelaunch. Some of the measured characteristics of this system were: a) a peak electric field on boresight of 4.2 kV/m at a range r =305 m, b) an uncorrected pulse rise-time (10-90%) of 99 ps, and c) a boresight electric fields FWHM of 130 ps.

The radiating system has now been more fully characterized with additional measurements and computations of near filed, intermediate and far fields on boresight. While the far fields from such a radiating system have been known for some time [2], the intermediate field analysis was published recently [3]. This method substitutes the radiated field from a paraboloidal reflector by the radiation field from the TEM structure reflected in the parabolic mirror. Although this work is limited to fields on the boresight at any distance from the antenna, we have been able to extend the analysis to frequency domain. It has also been verified that the intermediate fields asymptotically tend to the far-field expressions, as the range r is increased. Good agreement between the calculated and measured fields has been obtained for the Prototype IRA in the near (r = 5 m) and in the far field (r = 305 m).

I. A REALISTIC ANALYTICAL MODEL FOR THE PULSER

Transient pulse generators are typically specified with three numbers. They are: peak amplitude, the (10-90)% risetime and the FWHM. Such a characterization is ainadequate in the context of an impulse radiating antenna, where the far field is proportional to the maximum rate of rise of the voltage waveform launched on the antenna. This voltage could be different from the voltage out of the pulser owing to the presence of other dielectric media at the feed point. It then becomes important to assess the maximum value of the voltage rate of rise. So, instead of the usual double exponential model, we have used the following analytical model. The pulser voltage , its derivative and the Fourier transform are given by:

$$V(t)=\begin{cases} V_0 e^{-\frac{\beta t}{t_d}}\left[(1/2)erfc\left(\sqrt{\pi}|t|/t_d\right)\right] t<0 \\ V_0 e^{-\frac{\beta t}{t_d}}\left[1-(1/2)erfc\left(\sqrt{\pi}t/t_d\right)\right] t\geq 0 \end{cases} \quad (1)$$

$$\frac{dV(t)}{dt}=\frac{V_0}{t_d}e^{-\beta\left(\frac{t}{t_d}\right)}e^{-\pi\left(\frac{t}{t_d}\right)^2}-\frac{\beta}{t_d}V(t) \quad (2)$$

$$\tilde{V}(\omega)=\frac{V_0 t_d}{(\beta+j\omega t_d)}e^{\left[\frac{1}{4\pi}(\beta+j\omega t_d)^2\right]} \quad (3)$$

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14. ABSTRACT **Previously, the design, fabrication and testing of a pulser with a parabolic reflector antenna, known as Prototype Impulse-Radiating Antenna (IRA) had been presented [I]. The paraboloidal reflector was fed by a TEM structure that in-turn was energized by a t 60 kV, - 100 atm. hydrogen switch operating in a burst mode at up to 200 Hz. The TEM structure also incorporated an electromagnetic lens to ensure a nearideal spherical TEM wavelaunch. Some of the measured characteristics of this system were: a) a peak electric field on boresight of 4.2 kV/m at a range r =305 m, b) an uncorrected pulse rise-time (lo-90%) of 99 ps, and c) a boresight electric fields FWHM of 130 ps. The radiating system has now been more fully characterized with additional measurements and computations of near filed, intermediate and far fields on boresight. While the far fields from such a radiating system have been known for some time [2], the intermediate field analysis was published recently [3]. This method substitutes the radiated field from a paraboloidal reflector by the radiation field from the TEM structure reflected in the parabolic mirror. Although this work is limited to fields on the boresight at any distance from the antenna, we have been able to extend the analysis to frequency domain. It has also been verified that the intermediate fields asymptotically tend to the farfield expressions, as the range r is increased. Good agreement between the calculated and measured fields has been obtained for the Prototype IRA in the near (r = 5 m) and in the far field (r = 305 m).**		
15. SUBJECT TERMS		

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The above analytical model of the pulser, although still characterized by three numbers, has continuous derivatives and typical pulser outputs are well represented by this model. These numbers for the prototype IRA pulser are:

$$V_0 = 120.72\, kV;\ t_d = 100\, ps;\ \beta = 0.005 \qquad (4)$$

The resulting maximum rate of rise for this pulser is

$$(dV/dt)\text{max.} = 1.2 \times 10^{15}\ V/s \qquad (5)$$

The above outlined pulser model is used in computing the near, intermediate and far field on the boresight of the antenna.

II. THE PULSER AND THE ANTENNA SYSTEM

The key elements of this pulser and antenna system include the following:

- A high-pressure(~100 atm.), low-inductance rep-rate, hydrogen gas spark gap switch;
- Ceramic capacitors incorporated into feed lines;
- True differential charging and switch-out of the capacitor/switch elements;
- Fairly long burst (500 pulses, 200Hz)
- Use of plastics matched to the dielectric constant of the insulating oil;
- Charging of the system through the antenna;
- Paraboloidal reflector antenna (12 feet diameter) fed by a pair of conical transmission lines, connected in parallel, with a net impedance of 200 Ohms:

A detailed description of the system may be found in [1] and is not repeated here.

II. BORESIGHT FIELDS

Mikheev et. al, [3] have proposed a simple method for calculating the near, intermediate and far fields of an antenna like the prototype IRA. Basically, this method uses the conical transmission-line fields reflected in the parabolic mirror. If the antenna was a flat plate, the conical transmission-line would have an identical mirror image in the flat plate, resulting in the feed line and its image having the same expansion angle. However, since the antenna is paraboloidal in shape, the image is also a conical transmission line with a different expansion angle. The various geometrical parameters for boresight field calculations are shown in figure 1.

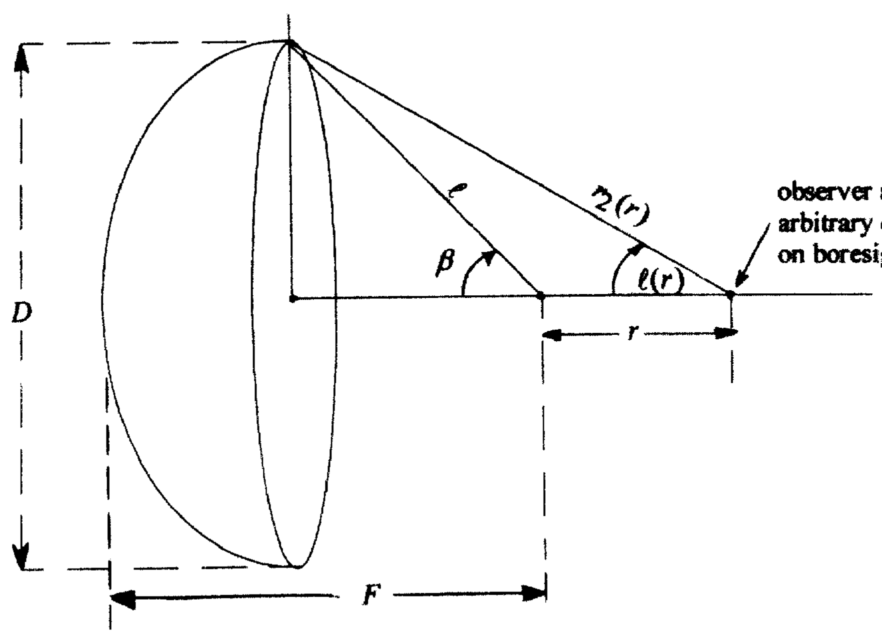

Figure 1. The geometry for boresight field calculations.

The total electric field at any point on the boresight axis, at a distance of r from the focal point is given by

$$E(\pi,t)=\frac{1}{2f_g\pi}\left\{\left[\frac{V\left(t-\frac{r}{c}\right)}{r}\,\frac{\sin(\beta)}{1+\cos(\beta)}-\frac{V\left(t-\frac{\ell}{c}-\frac{r_2}{c}\right)}{r_2}\,\frac{\sin(\beta)+\sin(\gamma)}{1+\cos(\beta-\gamma)}\right]-\left[\frac{4V\left(t-\frac{2F}{c}-\frac{r}{c}\right)}{D}-(2+2\cos\gamma)\frac{V\left(t-\frac{\ell}{c}-\frac{r_2}{c}\right)}{D}\right]\right\} \tag{6}$$

where the geometric impedance factor f_g is the ratio of the antenna input impedance Z_c to the characteristic impedance of free space Z_0, or $f_g = (Z_c / Z_0)$. It is noted that for a paraboloidal reflector,

$$\frac{\sin(\beta)}{1+\cos(\beta)}=\frac{D}{4F} \tag{7}$$

It should be noted that the clear time t for this antenna is defined by

$$t_c=\frac{\ell+r_2-r}{c} \tag{8}$$

This is the differential time of a ray that travels from the focal point to the observer and a ray that goes from the focal point to the reflector rim and then to the observer. The far field starts at a sufficiently large distance r, where t_c is small compared to the rise time of the voltage waveform. In practice we find that the far field starts when t_c is ~ (risetime/3). We have further verified that the field expression in equation (6) reduces to the familiar expression

$$E_r(\pi,t)\simeq\frac{D}{4\pi rcf_g}\left[\frac{\partial V\left(t-\frac{2F}{c}-\frac{r}{c}\right)}{\partial t}-\frac{c}{2F}\left\{V\left(t-\frac{r}{c}\right)-V\left(t-\frac{2F}{c}-\frac{r}{c}\right)\right\}\right] \tag{9}$$

when r is in the far zone. Now, substituting the voltage waveform *V(t)* from equation (1) into field expression in (6), we can get the boresight field at any arbitrary distance r from the focal point. This has been done with a straightforward computer code. We were also able to analytically Fourier transform the field expressions and compute the spectral domain fields as well. The computations have been made for various values of r = 5, 10,20,40,60,80,100, 120, 140, 160, 200, 220, 240, 260, 280, 300, 305, 320 and 400 meters. These range of values cover the near, intermediate and far fields. Representative results of calculations at range r = 5m, 20m, 200m and 305m are shown in figures 2 through 5.

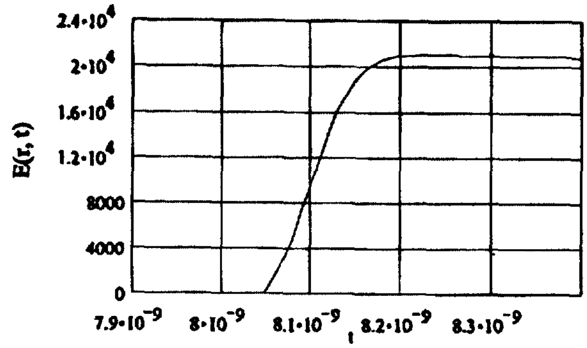

Figure 2. E-field at r = 5 m

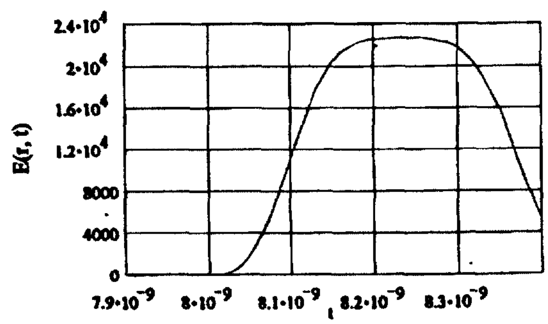

Figure 3. E-field at r = 20 m

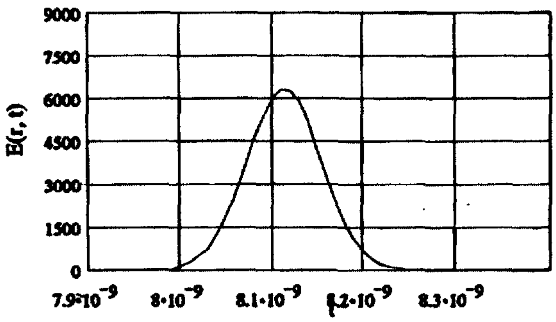

Figure 4. E-field at *r* = 200 m

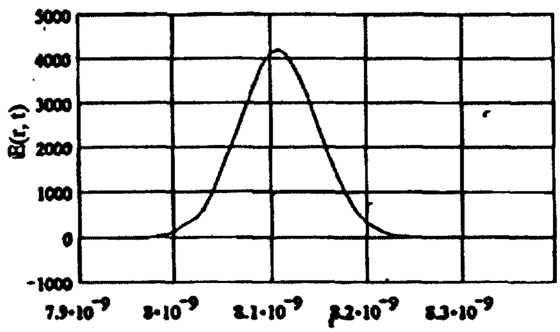

Figure 5. E-field at *r* = 305 m

Some comments about the results in the above figures are in order. In figure 2, we see that the electric field basically following the voltage waveform. At r = 20 m, it is seen that the electric field follows the voltage waveform, until such time the edge of the reflector is seen and this brings the e-field down. This process continues and the near field evolves into the intermediate and finally the far field. In the far field, the clear time is getting smaller and smaller, and this results in a differentiation of the voltage waveform. A measurement on boresight at a distance of r = 5 m was made and the measured time domain peak was found to be 22 kV/m, which is in agreement with the result in figure 2. The measured field at r = 305 m is shown in figure 6. It is seen to be in good agreement with the calculated results. The time-domain peak e-field and $V = (rE)$ are plotted in figures 7 and 8. It is observed that the near field peak remains constant for a certain distance from the antenna and then falls off at a rate slower than ($1/r$) and finally reaches the ($1/r$) fall off in the far field. The clear time t becomes one-third of the risetime at a range r = 167 m. This can be considered as the beginning of the far field.

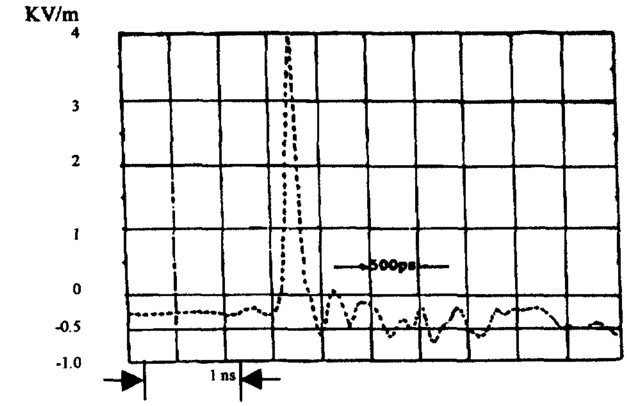

Figure 6. Measured electric field at *r* = 305 m

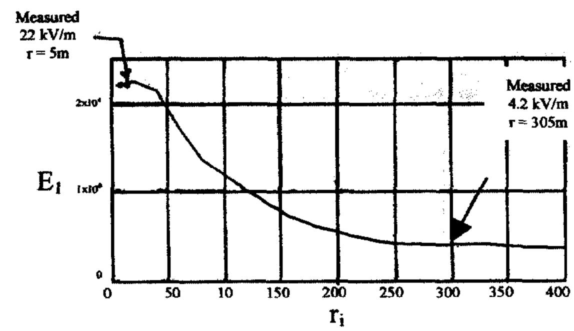

Figure 7. Peak e-field versus range *r*

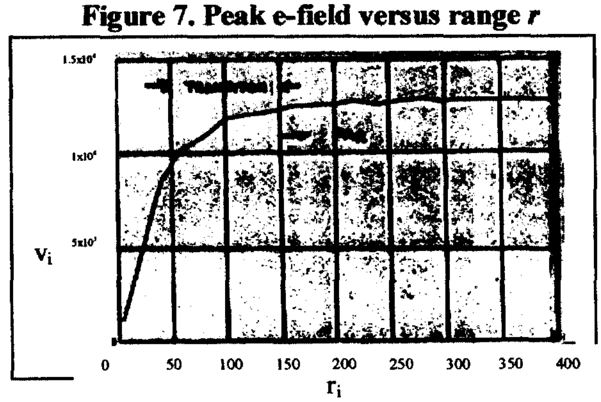

Figure 8. V = (rE) versus range r

[1] I.D.Smith, D.W.Morton, D.V.Giri, H.Lackner, C.E.Baum, J.R.Marek, " Design, Fabrication and Testing of a Paraboloidal Reflector Antenna and Pulser System for Impulse-Like Waveforms", Invited Paper, Proceedings of the Tenth IEEE International Pulsed Power Conference, held in Albuquerque, NM, July 3-6, 1995, volume 1, pp 56-64.

[2] C.E.Baum, "Radiation of Impulse-Like Transient Fields", Sensor and Simulation Note 321, 25 November 1989.

[3] O.V.Mikheev et al., "New Method for Calculating Pulse Radiation from an Antenna with a Reflector", IEEE Transactions on Electromagnetic Compatibility, volume 39, number 1, February 1997, pp 48-54.